

Edge AI-Based Smart Agriculture System

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Abstract – Agriculture plays an important role in food production, but farmers often face problems in checking soil conditions and managing crops properly. The proposed Edge AI based Smart Agriculture System is developed to help farmers in simple and smart farming. In this system, an ESP32 controller is connected with soil moisture, pH, and NPK sensors to collect soil data from the field. The collected data is processed near the system using Edge AI, which provides faster results and reduces internet usage. Based on the sensor values, the system helps farmers understand soil conditions and choose suitable crops. It also supports automatic irrigation to reduce water wastage. The system can help in checking market prices for better crop planning. Farmers can monitor field details through cloud platforms from remote locations. This method reduces manual work and saves time. It also helps in improving crop growth and field management. The system is simple, useful, and affordable for farming purposes. Overall, this smart agriculture system helps farmers make better decisions and improve farming productivity in an easy way.

Key Words: Edge AI, ESP32, Smart Agriculture, Automatic Irrigation, Soil monitoring, Crop Recommendation, NPK Sensor, IoT (Internet of things) Agriculture.

1. INTRODUCTION

Agriculture is an important part of our daily life. In earlier times, farming was done manually using simple tools and traditional methods. Farmers mainly depended on rainfall, weather conditions, and their own experience to grow crops. These methods helped farming for many years, but farmers found it difficult to identify plant diseases or sudden climate changes. Because of this, crops were sometimes damaged, which led to financial losses for farmers.

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The main aim of this project is to develop a smart agriculture system using Edge AI technology. This system

can automatically monitor crop conditions, identify diseases at an early stage, and use water and other resources properly. Compared to traditional farming methods, this system helps save time, reduce manual work, and increase crop production. It also supports eco-friendly and smart farming practices.

In the future, Edge AI based smart agriculture systems can help solve many problems in farming. These systems help farmers save water, reduce hard work, and improve crop growth. By using smart technology, farming becomes easier, faster, and more efficient. It also helps farmers increase crop production with less cost and effort.

2. LITERATURE REVIEW

[1] AI Powered Smart Farming Ecosystem – K. Mahanta, S. S. Hussain, and A. G (2026).

The system combines advanced artificial intelligence with Internet of Things infrastructure to improve automatic monitoring, crop management, and resource allocation. By leveraging a network of smart sensors distributed across the fields, it collects real-time data on environmental factors such as temperature, humidity, and soil conditions. This data is then analysed using machine learning models to provide useful information for predictive analytics, empowering farmers to transition from traditional practices to precise, data-driven strategies. Ultimately, this comprehensive digital framework aims to improve efficiency daily agricultural workflows, minimize overhead costs, and significantly increase total crop yield while laying a strong technical foundation for long-term economic and environmental sustainability in modern farming practices.

[2] Comprehensive Review of Vision and IoT Based Smart Soil Nutrient and Crop Monitoring: Challenges and Opportunities – L. Khetawat and J. Joshi (2025).

The system evaluates computer vision techniques and sensor integrations to track macro-nutrients and plant health, identifying critical systemic bottlenecks and growth opportunities within next-generation digital agronomy. By analyzing high-resolution imagery alongside real-time soil data, the research highlights how optical sensors can detect subtle changes in leaf pigmentation and soil composition before visible degradation occurs. The paper provides an in-depth analysis of current obstacles such as high hardware costs, computational limitations on-site, and the difficulties of operating in erratic outdoor environments.

[3] Smart Farming with IoT and AI: Enhancing Precision Agriculture through Sensor Networks – C. H. Sirisha, M. Soujanya, H. M. Ganesh Kumar (2025).

The system utilizes distributed sensor deployments and localized machine learning algorithms to balance real-time ecological data, enabling automated adjustments to irrigation and fertilization based on immediate field conditions. The architecture relies on an interconnected array of low-power sensor nodes that consistently capture micro-climatic shifts across diverse cultivation zones. By utilizing intelligent processing loops, the system effectively bridges the gap between field telemetry and autonomous machinery, ensuring that resources are distributed precisely where and when they are needed. This integration reduces chemical runoff and over-watering, helping farmers protect local water tables and soil quality while maintaining optimal growing environments for their crops.

[4] AIoT-Enabled Data Management for Smart Agriculture: A Comprehensive Review on Emerging Technologies – X. Luo, S. Xiong, X. Jia, Y. Zeng, and X. Chen (2025).

The system leverages hierarchical data management architectures and artificial intelligence of things (AIoT) paradigms to securely store, process, and optimize data streams coming from sprawling, heterogeneous sensor nodes across the field. The study deeply explores the convergence of cloud storage, edge computing, and artificial intelligence, demonstrating how modern agricultural setups can handle massive influxes of unstructured field data without experiencing bandwidth congestion. Additionally, the paper highlights advanced data aggregation and compression methodologies that preserve critical telemetry information while reducing network stress. This comprehensive review serves as a technical blueprint for building resilient, high-capacity data pipelines capable of supporting complex autonomous operations in large-scale commercial farming.

[5] An Ensemble Formal Approach to Improve Energy Efficiency and Data Aggregation in Smart Agriculture – S. Ahmad et al. (2025).

The system minimizes network energy overhead and battery depletion risks through mathematically verified ensemble communication models, guaranteeing reliable data routing without compromising the lifespan of localized agricultural sensors. Recognizing that wireless sensor networks in rural areas often suffer from limited battery capacities and high replacement costs, the authors introduce a three-phase routing and aggregation strategy. This method groups sensors intelligently into clusters and uses formal verification to mathematically prove that data loss

and idle energy consumption are minimized. By maximizing the lifetime of each deployed node, this approach ensures continuous field monitoring, making large-scale smart farming networks highly practical and cost-effective over long periods.

[6] Development of a Low-Cost Real-Time Crop Detection System Using SSD-Based Deep Learning on a Compact UAV – D. Yodoshi and S. Nishide (2025).

The system moves high-speed visual inference to lightweight drones, utilizing Single Shot MultiBox Detector (SSD) algorithms to monitor vast crop fields and detect anomalous patches or diseases without needing expensive ground setups. By mounting optimized, lightweight deep learning models directly onto compact unmanned aerial vehicles, the system achieves real-time aerial object detection and field mapping at a fraction of the cost of traditional satellite or manned aircraft surveillance. The drone can autonomously navigate pre-programmed flight paths, capture high-resolution imagery, and instantly classify crop health or locate weed infestations on-site. This approach provides small-scale and resource-constrained farmers with a highly mobile, affordable, and immediate bird's-eye view of their fields to enable rapid intervention.

[7] Smart irrigation for soil moisture prediction using hybrid AI and fog computing – R. Bindal, M. Kaur, and R. Tandon (2025).

The system bypasses traditional cloud latencies by bringing machine learning algorithms down to local fog nodes, allowing real-time irrigation planning and dynamic soil moisture forecasting based on local environmental fluctuations. By using a hybrid artificial intelligence model that combines time-series forecasting with historical environmental variables, the system predicts moisture depletion rates with high precision. The localized fog computing tier ensures that data processing happens near the field, keeping irrigation controls operational even during unstable internet connections. This layout eliminates the delays and bandwidth costs of cloud-only systems, allowing for quick adjustments to watering schedules that protect crops from water stress and optimize resource use.

[8] Soil Moisture-Based Intelligent Irrigation System with IoT and Cloud Computing for Precision Agriculture and Water Conservation – M. Janani, Mounika V., U. D., and M. Benisha (2025).

The system pairs cloud intelligence with real-time moisture telemetry, enabling target-oriented valve controls that save vital water resources while ensuring crops remain in optimal hydric conditions. Through an array of moisture and temperature sensors embedded in the root zones, data is continuously streamed to a centralized cloud platform where complex predictive models calculate exact evapo-

ration rates. The cloud interface then sends automated commands back to field actuators to manage water delivery. This creates an efficient closed-loop system that cuts down on human error, prevents water waste, and supports global water conservation efforts while ensuring stable crop yields.

[9] Artificial Intelligence and Internet of Things Powered Smart Irrigation: Transforming Agricultural Efficiency and Sustainability – Ouremchi, M. Fattah, M. Mahfoudi, and M. E. Bekkali (2025).

The system addresses critical climate change and ground-water scarcity concerns by establishing an automated closed-loop irrigation architecture driven by an ESP32 microcontroller. Utilizing data acquisition from soil moisture, DHT11 temperature/humidity, and water level sensors, the system performs real-time telemetry processing to dynamically open or close water valves. Crucially, the platform factors in rainfall predictions and precipitation probabilities to completely halt unnecessary water deployment during rainy weather conditions, avoiding overwatering and conserving key resources. To combat isolation in remote agricultural settings and reduce dependency on traditional power grids, the authors fully integrate solar energy harvesting assets into the embedded hardware layout.

Smart Agriculture: Current State, Opportunities, and Challenges – B. Ahmed, H. Shabbir, S. R. Naqvi, and L. Peng (2024).

The system provides an end-to-end overview of modern technological bottlenecks in farming, discussing the interplay of AI, robotics, and market readiness while mapping out strategic paths to overcome infrastructural limits. The authors examine how global food security challenges can be addressed by integrating unmanned tractors, automated weeders, and satellite-based crop analytics into daily routines. They also look at major adoption barriers, such as high initial costs, the lack of digital literacy among farmers, and missing rural internet infrastructure. By synthesizing recent breakthroughs alongside practical economic realities, this study serves as a foundational guide for researchers and policymakers looking to design scalable, inclusive, and realistic technologies for the future of farming.

[10] AgroXAI: Explainable AI-Driven Crop Recommendation System for Agriculture 4.0 – O. Turgut, I. Kök, and S. Özdemir (2024).

The system enhances machine learning models with explainability layers, allowing farmers to not only receive accurate crop type suggestions based on environmental conditions but also understand the underlying climatic and soil data reasoning behind those choices. Traditional

“black-box” machine learning algorithms often generate predictions without context, making it difficult for farmers to trust their suggestions. AgroXAI solves this by incorporating explainable artificial intelligence (XAI) frameworks that explicitly break down how variables like soil pH, rainfall, and nitrogen levels influenced a specific recommendation. This transparency builds trust with agricultural workers, helps reduce financial risks during crop rotation, and makes data-driven decision-making accessible to non-technical users.

[11] Artificial Intelligence and Internet of Things for Sustainable Farming and Smart Agriculture – A. A. Alzubi and K. Galyna (2023).

The framework pairs AI decision pipelines with IoT networks to optimize long-term ecological outcomes, reducing waste and toxic chemical runoff through highly localized, precision treatments of crops. The system tracks historical weather patterns alongside real-time moisture and pest data to help farmers implement targeted pesticide and fertilizer application schedules. By moving away from uniform field spraying and toward micro-dosing, the model protects surrounding ecosystems and groundwater from chemical pollution. This balanced blend of IoT telemetry and predictive AI shows how modern commercial farms can maximize productivity while keeping their ecological footprint low and maintaining soil fertility for future generations.

[12] Smart Farming based on AI, Edge Computing and IoT – G. Kumar T and K. V. Shashank (2022).

The system offloads critical compute tasks from remote servers to edge-level processing nodes, reducing network dependency and latency issues to deliver real-time actionable insights straight to the field. By placing microcontrollers and localized edge processors directly adjacent to field sensors, the architecture can interpret data streams and trigger automated agricultural machinery instantly without waiting for cloud validation. This design choice is valuable for remote rural regions where cellular networks are often slow or unreliable. By enabling offline functionality and fast data processing, this edge-driven framework ensures that smart irrigation, greenhouse climate adjustments, and automated security monitoring remain steady and active under any network conditions.

[13] Internet of Things for the Future of Smart Agriculture: A Comprehensive Survey of Emerging Technologies – O. Friha, M. A. Ferrag, L. Shu, L. Maglaras, and X. C. Wang (2021).

The system provides an extensive and exhaustive analysis of how Internet of Things (IoT) frameworks can be systematically applied to modernize global agricultural practices. The research maps out a multi-layered

ecosystem that integrates state-of-the-art technologies including unmanned aerial vehicles (UAVs), wireless sensor networks, and edge-to-cloud computing environments to handle agricultural challenges. Furthermore, the paper deeply investigates critical architectural challenges, such as ensuring rigorous cybersecurity across remote physical nodes, optimizing network topologies for rural connectivity, and maintaining interoperability among heterogeneous hardware devices. By reviewing modern standards, emerging platforms, and open research challenges, this comprehensive survey serves as a vital technical manual for designing secure, highly scalable, and energy-efficient digital architectures tailored for future large-scale smart farming environments.

3. CONCLUSIONS

This project presents an Edge AI Based Smart Agriculture System designed to improve farming through real-time monitoring and intelligent decision-making. The proposed solution combines Edge AI, IoT devices, and machine learning techniques to collect and process information from soil moisture, temperature, humidity, pH, and NPK sensors. Since data is analysed locally at the edge, the system can respond more quickly, reduce dependence on continuous internet connectivity, and provide timely recommendations for farm management.

The developed system also includes an automatic irrigation mechanism that supplies water only when soil conditions require it. This approach helps conserve water, lowers unnecessary energy consumption, and minimizes human intervention.

In addition to field monitoring, the system incorporates a market analysis feature that estimates crop price trends and supports farmers in selecting suitable crops and planning the best time to sell their produce. Combining environmental monitoring with market-based insights enables more informed agricultural decisions.

The proposed model is designed to be cost-effective, practical, and suitable for farms of different sizes. By integrating sensor-based monitoring, intelligent data processing, automated irrigation, and market forecasting into a single platform, the system aims to improve resource utilization, increase crop productivity, and enhance farmers' income. This work demonstrates the potential of Edge AI to support efficient, sustainable, and technology-driven agricultural practices while addressing the growing need for smart farming solutions.

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